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A HUMAN FACTORS NEEDS ASSESSMENT AND PLANNING STUDY

by

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RESEARCH REPORT

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But wherever we looked, we found problems with the human beings who operate the plant, with the management that is charged with assuring the safety of nuclear power plants . . . For example, in 1952 an operator's mistake led to the withdrawal of some control rods in a Canadian research reactor. The ensuing surge of nuclear reactivity then caused a partial melt-down and contaminated the reactor site with radioactivity. The Windscale fire of 1957 was triggered by an operator raising the power level too quickly . . . And the fire at Brown's Ferry, Alabama, in 1975, which disabled many of the reactor's controls, was caused by an electrician's candle.[1]

- Sir Alan Cottrell, FRS

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[1]Cottrell, A. How safe is nuclear energy? Heinemann, London, 1981.

A HUMAN FACTORS NEEDS ASSESSMENT AND PLANNING STUDY

ABSTRACT

A study was done to assess the need for human factors research, development, and regulatory action in the Atomic Energy Control Board. Further study or development in nine human factors areas is proposed. The urgency, schedule, and resources judged to be necessary for the proposed efforts are estimated. Special emphasis is placed on the need for task analysis information, for the evaluation of control room and maintenance human engineering, and for the development of an improved human error reporting system.

RÉSUMÉ

Une étude a été entreprise pour évaluer le besoin de recherches en ergonomie par rapport aux activités de réglementation de la Commission de contrôle de l'énergie atomique. L'exposé traite de neuf projets d'études plus poussées ou d'améliorations envisagées en ergonomie, puis évalue l'urgence, le calendrier et les ressources nécessaires dans chaque cas. Une importance toute particulière est accordée à la nécessité d'obtenir des renseignements dérivés de l'analyse des tâches, tant pour mieux évaluer les conditions ergonomiques de la salle de contrôle et de la maintenance, que pour perfectionner le système actuel de compte rendu des erreurs humaines.

DISCLAIMER

The Atomic Energy Control Board is not responsible for the accuracy of the statements made or opinions expressed in this publication and neither the Board nor the authors assume liability with respect to any damage or loss incurred as a result of the use made of the information contained in this publication.

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SECTION 1
INTRODUCTION

Objectives of Study

This report is the outcome of a study to assess the needs of the Atomic Energy Control Board (AECB) in the area of human factors. Its purpose was to provide the industry and AECB with an initial basis for developing human factors research, development, and regulatory plans. The objectives of the study were to: (1) assess the extent and nature of the application of human factors in the Canadian nuclear industry and in the regulatory activities of the AECB; (2) identify human factors problems likely to affect plant availability, reliability, and safety; and (3) propose goals, a strategy and plans, resources, and schedules for actions aimed at minimizing human error and its consequences for plant and public safety and health.

Scope

This study was limited in duration and in scope to a period of two months and to as much information as could be gained from a variety of sources during two brief visits to the AECB and to one nuclear power station. The accuracy and adequacy of observations, conclusions, and recommendations based on limited evidence are naturally subject to debate. However, to the extent to which our extensive experience with human factors problems and solutions in the nuclear industry in the United States can be generalized to Canada, our findings and recommendations may be valid. We have attempted to present them in light of our understanding of the substantial differences in reactor technology and operation and in regulatory philosophy and practice between Canada and the United States.

Background

On January 8, 1982, Dr. David J. Martin of the AECB visited BioTechnology, Inc. (BTI), to discuss the application of human factors in the AECB and Canadian nuclear industry and to evaluate BTI's experience and capability in the application of human factors to power plants.

On January 29, Harold E. Price, Vice President and General Manager of BioTechnology, and Harold P. Van Cott, Chief Scientist, visited AECB Headquarters in Ottawa and briefed staff on the work BioTechnology and the Human Factors Society had done in the area of human factors in nuclear power plants.

On March 22, 1982, BioTechnology received a research contract from the AECB to conduct a human factors needs assessment study. Accordingly, Mr. Price and Dr. Van Cott spent April 5 to 7 at AECB Headquarters in Ottawa and April 8 at the Pickering Nuclear Station near Toronto for the purpose of gathering information.

Approach

Before and after receipt of the contract, BTI received a substantial number of AECB papers, presentations, reports, and regulatory documents. These proved to be a useful source of information that provided us with a perspective on the AECB's philosophy and approach under the Atomic Energy Control Act and on the actions that had been considered or taken to minimize human error.

Between April 5 and 7, we also interviewed the following Board staff:

- R.J. Atchison
- F.C. Boyd
- M. Chandra
- F. Davediuk
- R.M. Duncan
- P.E. Hamel
- J.D. Harvie
- J.H. Jennekens
- D.J. Martin
- T.J. Molloy
- R.A. Thomas
- J.G. Waddington
- A. Wild.

At each interview we presented the person whom we interviewed with the description of representative human factors areas which follows. This focused the meeting around the issues that form the basis for organizing this report.

1. Human Performance Requirements

Those nuclear power plant features that impose demands for human performance during operations or maintenance. Specific issues of concern include:

- Level of automation in the allocation of functions to man and machines
- Task analysis and the requirements for specific human performance
- Human reliability
- Human performance evaluation criteria.

2. Human Factors Engineering

The man/machine interface and those design features that particularly affect human performance such as controls and displays, workspace layout, and environmental factors. Specific issues of concern include:

- Design-induced error
- Annunciators and alarms
- Systems status monitoring
- Design for maintainability
- Work area performance shaping factors.

3. Job Performance Aids

Those means of extending human capability by providing (1) a mechanism for storing information for later use on the job, or (2) a technique for pre-processing information to facilitate dec sionmaking. Specific issues of concern include:

- Operating and maintenance procedures development, validation, and revision
- Operator decision aids for change of state detection, diagnosis, reconfiguration, and verification
- Information presentation formats for procedures and aids
- Change of shift procedures.

4. Qualitative and Quantitative Personnel Requirements

The determination of the types, numbers, and organization of personnel to ensure initial and continuing performance quality of all categories of plant personnel. Specific issues of concern include:

- Personnel selection practices and standards
- Staffing and organizational characteristics
- Shift duration and rotation
- Factors affecting job satisfaction
- Qualifications of utility management.

5. Training and Licensing

The development and conduct of training for personnel involved in the operation and maintenance of the plant. This area also includes the certification and licensing of selected personnel. Specific issues of concern include:

- Instructional systems development
- Licensed personnel training
- Non-licensed personnel training
- Simulator and training equipment
- Personnel certification and licensing.

On April 8 at the Pickering Plant, we visited the Ontario Hydro Information Centre, and an operational control room; met with Mr. Jim Thorpe, a first operator; were given a plant tour by Mr. Colin King, a former operator; and observed the plant simulator facility and discussed training with Mr. Mickey Bonner, a simulator training technician. Also on the 8th, we met informally for lunch with two human factors specialists from Ontario Hydro.

At each point throughout this visit, we received valuable information from our discussions and observations in the form of reports, papers, and documents that were given to us.

Following this trip, we reviewed once again all of our documentation and notes and undertook the development of this report.

Regulatory Basis

The responsibility and authority for consideration of human factors by the AECB seem well-founded in the Atomic Energy Control Act, regulations administered by the Atomic Energy Control Board, and other regulatory documents. The following illustrations have been extracted to support this contention.

Atomic Energy Control Regulations, Part 3

This document identifies the licensing requirements for:

(a) A description of the operating procedures of the nuclear facility

(b) A description of the qualifications, training, and experience of any person involved in the operation of the nuclear facility.

Regulatory Policy Statement, The Use of Two Shutdown Systems and Reactors

This document states interalia that "'manual actuation' is acceptable as a 'trip parameter' provided it is shown that adequate information and time are available to alert an operator and to permit him to assess the need for intervention and to actuate the protective shutdown system manually."

Regulatory Guide, Requirements for the Safety Analysis of CANDU Nuclear Power Plants

References are made to three human factors requirements in this document. Paragraph 4.3 states that the analysis of each event shall include determination of "the necessary operator actions, indications available to identify the need for such actions, and the period of time between the indication and the point when the operator must begin taking action." Paragraph 4.9 states that the analysis of each event shall include the determination of the credible event sequences taking into account "operator error." Paragraph 5.0 states that the rules for performing safety analysis shall include "the assumed response of the operator taking into account items such as plant indications, response time, and procedures."

Proposed Regulatory Guide, Requirements for Containment Systems for CANDU Nuclear Power Plants

This guide has two requirements with human factors implications. Paragraph 2.12 states that "the design of the containment system shall be such that the status of important equipment can be monitored from the control room." Paragraph 3.1b states that "procedures for taking corrective action, in the event that containment is found to be unavailable when the above conditions are met, shall be prepared and shall require approval by the AECB." Paragraph 3.2 states that all of the following requirements must be met in the event that operator action is required:

1. The containment system instrumentation shall be designed to give the operator clear and unambiguous indication of the necessity for operator action.

2. Operation actions shall not be required within fifteen minutes of such clear and unambiguous indication.
3. There shall be clear, well-defined, and readily available operating procedures to identify the necessary actions.

Proposed Regulatory Guide, Requirements for Shutdown Systems for CANDU Nuclear Power Plants

This guide has two requirements with human factor implications. Paragraph 2.7 describes status monitoring requirements as follows:

a. The design of a shutdown system shall be such that the status of all important equipment required for its actuation can be monitored or inferred from the appropriate control room.
b. As far as practicable all failures of shutdown system components which may interfere with proper functioning of the shutdown system shall be annunciated in the control room.

Paragraph 3.2, the requirement for accident conditions, states, "operator action shall not be necessary for any function associated with shutting down the reactor in accident conditions."

Proposed Regulatory Guide, Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants

This document contains three requirements with implications for human factors. Paragraph 2.4 which states availability requirements contains the following two statements:

(h) The design shall be such that all necessary actions of ECCS equipment which are initiated by automatic control logic can also be initiated manually from the appropriate control room.

(i) The design shall be such that, in the event of an accident, it is not readily possible for an operator to prevent a safe automatic action from taking place.

Paragraph 2.9 states the following status monitoring requirements:

(a) The design of the ECCS shall be such that the status of important equipment required for operation of the ECCS can be monitored from the control room.

(b) As far as practicable all features of ECCS components which may interfere with proper functioning of the ECCS shall be annunciated in the control room.

Paragraph 3.2 states that in the event operator action is required for actuation of any ECCS function, the following requirements must be met:

(a) The ECCS instrumentation shall be designed to give the operator clear and unambiguous indication of the necessity for operator action.

(b) Operator action shall not be required within fifteen minutes of such clear and unambiguous indication.

(c) There shall be clear, well defined operating procedures to identify the necessary actions.

Statements such as these lead us to the conclusion that the Board has the statutory responsibility and authority to consider human factors issues and to undertake those regulatory actions in that area which are in keeping with these statements and within the resources available to the Board.

SECTION 2

HUMAN ERROR: A FACTOR IN PLANT SAFETY AND EFFECTIVENESS

Human factors is generally concerned with optimizing human performance in complex systems by (1) accounting for human capabilities, limitations, and attitudes in determining the role of personnel, and (2) designing and developing the operational and support systems to achieve and maintain the required personnel performance. The design and operation of commercial nuclear power plants generates a number of human factors areas of concern.

Human Error and Safety

It is generally accepted that 70-85 percent of all system failures are caused by human error. A small percentage of this total is random error due to noise in the human system that cannot be controlled. A much larger percentage of human error (between 55 and 65 percent) is attributable to such human factors design problems as: a misallocation of functions to man and machine, improper engineering of the man/machine interface, improper training, or poor personnel selection practices. These causes of error can be controlled and reduced--if not eliminated altogether--by the timely application of human factors engineering in design and operation.

Within the past decade, government and industry have become increasingly concerned with accident prevention, mitigation, and improved productivity. As a result, substantial progress is being made in the areas of safety engineering and automation. However, until the accident at the U.S. Three Mile Island nuclear power facility, much less attention was given to the function of

the people in systems and their relation to safety. While the Canadian commercial nuclear power industry has had an excellent long-term record of safety, the potential severity of accident consequences necessitates a continuing effort to optimize system safety factors. This most certainly includes the human factor as it is the ultimate last line of defence in the defence-in-depth concept. In order to illustrate the relationship between human error and system safety, a brief review of that relationship follows.

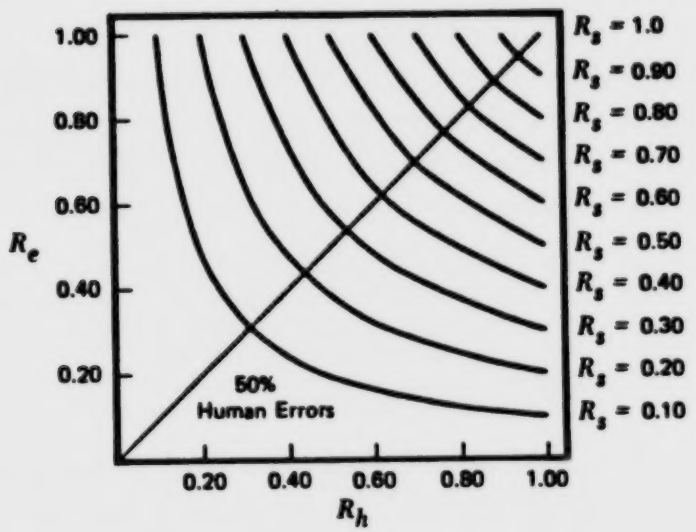
The relative impact of human error on system reliability has been shown graphically by Meister and Rabideau. In their report (1965), they discuss this graph (Exhibit 2.1) as follows:

> . . . It shows the relationship between human reliability R_H and equipment reliability R_E and their contribution to overall system reliability R_S. Thus, an R_E of .85 coupled with an R_H of .90 produces an R_S of approximately .77. Lower the human reliability to .30 with the same equipment reliability of .85, and system reliability now becomes .25. It is apparent, therefore, that anything which decreases R_H must be a primary concern of the human engineer. It is assumed that much of this error results from inadequacies in system design which create favorable conditions for error occurrence.
>
> Error potentiality resulting from inadequate design can only be eliminated by systematic and continuing evaluation through the development of that design. If the human factors aspects of system performance are not routinely evaluated, it is very likely that they will be overlooked, with the result that the particular system function involved will be developed inefficiently.

Human error is a recognized concern in many areas. A few selected studies concerning the human factors issue are presented here.

Exhibit 2.1

Effect of Human and Equipment Reliability on System Reliability: $R_e \times R_h = R_s$



$R_e R_h = R_s$

R_e = Equipment Reliability

R_h = Human Reliability

R_s = System Reliability

Based on a Sandia investigation of human errors which analyzed a large number of production defects at the plant of an Atomic Energy Commission prime contractor, Swain (1980) found that 82 percent of the defects could be directly attributable to human error.

Meister and Rabideau (1965) discuss the problem of human error and develop the link between human error and human factors and system effectiveness. They quote some human error percentages from other sources which estimate that:

> . . . 40% of the problems uncovered in missile testing derive from the human element. 63.6% of the (shipboard) collisions, flooding and grounding could blamed on human error. Reports produced by United States Air Force indicate that human error was responsible for 234 of 313 aircraft accidents during 1971. *(p. 15)*

In a classic study by Shapero et al. (1960), a survey of nine Air Force missile systems showed that human error contributed from 20 to 53 percent of system unreliability. These percentages referred only to human errors during field exercises with these systems, i.e., errors during the R&D launch or prelaunch activities.

The most celebrated of recent near-catastrophes involving human factors was the Three Mile Island accident. The Nuclear Regulatory Commission's report (1979) stated that:

> Although the accident at Three Mile Island stemmed from many sources, the most important lessons learned fall in a general area the task force chose to call operational safety. This general area includes the topics of human factors engineering; qualification and training of operations personnel; integration of the human element in the design, operation, and regulation of system safety; and quality assurance of operations. *(p. 31)*

Many studies have documented the relationship between human error and system effectiveness, reliability, or safety. It is believed that the few studies noted above are sufficient to make the point about the importance of human factors. More to the point is the experience with human factors or human error that has been documented in the operation and maintenance of nuclear power facilities. Unfortunately, there is little direct empirical data concerning the performance of humans in nuclear generating facilities. However, sufficient evidence has been built up through observation, analysis, or empirical performance measurement to clearly establish the human factor as a key issue in nuclear power plant safety. A brief review of the United States experience and the Canadian experience is discussed in the sections which follow.

United States Experience with Human Error in Nuclear Power Plants

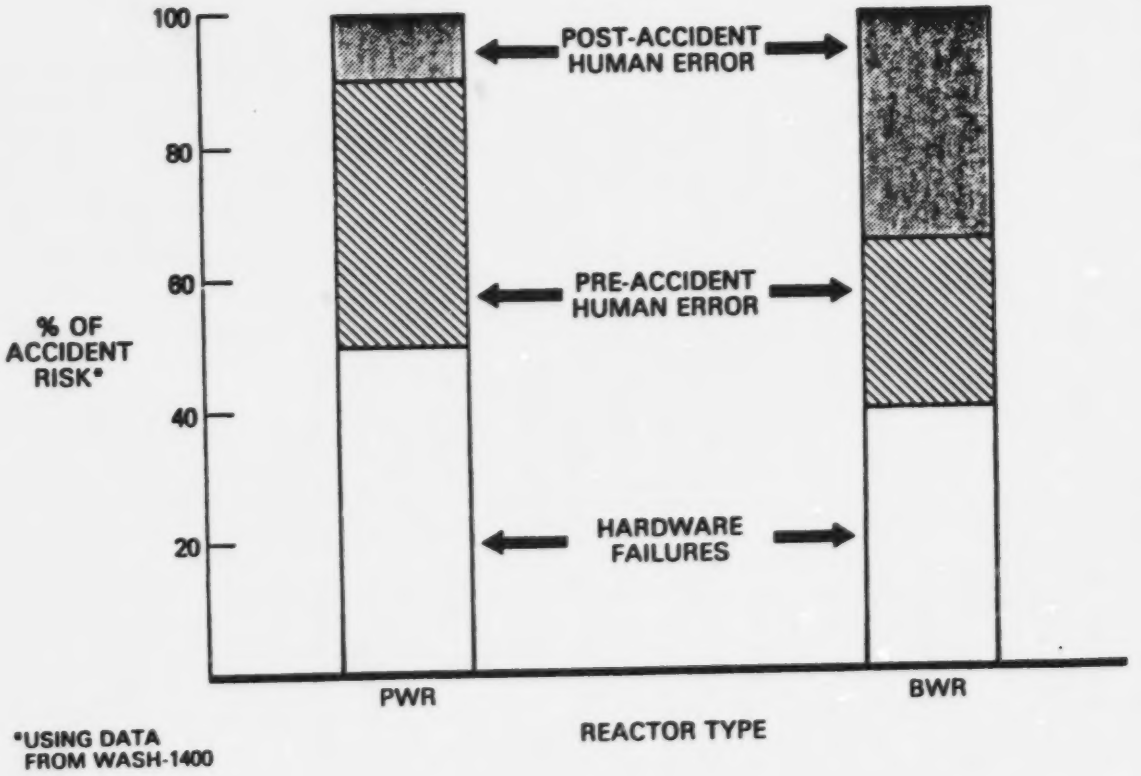
Obviously, there are differences between nuclear power plants in the United States and Canada. However, from a practical point of view, these differences are not great when the demands on the personnel involved in the operation and maintenance of the two types of plants are compared. In both cases the human being is an intricate part of a complex system. The design of the man/machine interface, the procedures, the training, and other factors affecting human performance are all quite similar in their impact on human behavior even through they may differ physically. Thus, we believe that the human error data available for U.S. nuclear power plants is relevant to Canadian power plants.

WASH-1400 was a landmark study of probabilistic risks in nuclear power plants. The objective of the study was to make a realistic estimate of the public risks that could be involved in potential accidents in commercial nuclear power plants. The results of this study clearly showed that human reliability was a major contributor to overall system reliability. This conclusion is summarized in Exhibit 2.2. This chart was developed by summing the probability and consequences of all the sequences in WASH-1400 which would equate to the total risk. The risk was then proportioned among human errors and hardware failures. It can be seen that improving human error can have a significant impact on reactor safety. The pre-accident human errors were those made prior to initiation of the event, such as the mispositioning of valves and safety systems or the incorrect calibration of sensors designed to trigger safety systems. Thus, many of these were test and maintenance errors. Post-accident errors occurred after the initiating event. For example, in some designs the ECCS came on automatically and injected water into the core. Eventually the water source was exhausted and the operator had to switch to another supply. Failure to do so was a post-accident error.

Since human error is only factored in to the extent that it contributes to the unavailability of safety systems on demand, this chart <u>may</u> underestimate the contribution of human error. For example, a reactor trips and the ECCS is required but is not available. In WASH-1400 the contribution of human error to the initiating event which caused the trip was not considered. Rather, it was assumed that some transient occurred and the contribution of human error was ignored.

Exhibit 2.2

IMPROVING THE OPERATOR-MACHINE INTERFACE CAN SIGNIFICANTLY ENHANCE REACTOR SAFETY



Analyses of licensee significant event reports have consistently concluded that approximately 20 percent of these events are attributable to human error (Udell, 1981; Potash, 1981). A good general summary of the operator error problem as determined from LERs is indicated by data developed by Sabri (1979) and shown in Exhibit 2.3.

More recently the Brookhaven National Laboratory has examined both the number of reported human errors and the opportunity for human errors. Exhibit 2.4 shows a summary of human errors associated with safety system components. The numbers in parentheses in the chart indicate the number of human errors over those that were initially coded as human errors in event reports. This later error estimate was arrived at by combining event reports with internally prepared plant reports. It can be seen that the actual count of human errors is four or five times greater than the number coded in the LER reports alone. After obtaining exposure data, Brookhaven estimated the human error rates as shown in Exhibit 2.5.

The most dramatic U.S. experience with human error occurred in the Three Mile Island accident. In our opinion, the fundamental human error at TMI-2 was a lack of recognition that a nuclear power plant is a man/machine system in which the design of that system for man is as important as the design of the machine. Similar views were expressed by the various commissions and inquiry groups that investigated the accident. TMI-2 human error problems have been well-documented and publicized and the implications for CANDU reactor safety have been well-analyzed in a report by Pannell and Campbell (1980) of the AECB. Many of the recommendations in their analysis parallel those contained in this report.

Exhibit 2.3

OPERATOR ERRORS RECORDED FROM JANUARY 1972 THROUGH DECEMBER 19, 1977

SYSTEM / COMPONENT INVOLVED	NUMBER OF EVENTS		TOTAL	PERCENT OF TOTAL NUMBER OF OPERATOR ERRORS
	BWR (100 PLANT-YEAR)	PWR (77 PLANT-YEAR)		
SYSTEM				
EMERGENCY CORE COOLING INJECTION SYSTEM	37	74	111 (48 VALVES)	21
WASTE PROCESSING SYSTEM	34	35	69 (38 VALVES)	13
INSTRUMENTATION AND MONITORING SYSTEM	34	27	61	12
REACTOR POWER CONTROL SYSTEMS	23	32	55 (29 CONTROL ROD DRIVE)	11
SECONDARY NON-NUCLEAR SYSTEMS	10	30	40	8
REACTOR PROTECTION SYSTEMS	20	16	36	7
AUXILIARY ELECTRIC POWER SYSTEM	15	19	34	7
MAIN REACTOR COOLANT SYSTEM	10	20	30	6
AUXILIARY SYSTEMS FOR NORMAL OPERATION	4	23	27	5
OTHER CONTAINMENT SYSTEMS	12	13	25	5
CONTAINMENT SPRAY AND RECIRCULATION SYSTEMS	1	21	22	4
EMERGENCY COOLING RECIRCULATION SYSTEMS	11	0	11 (10 TORUS)	2
TOTAL (SYSTEMS)	211	310	521	100

FROM: ANALYSIS OF 12,004 LER'S REPORTED BY SABRI IN TRANSACTIONS OF THE AMERICAN NUCLEAR SOCIETY, VOL. 33 (1979), 562.

Exhibit 2.4

SUMMARY OF NUMBERS OF REPORTED HUMAN ERRORS ASSOCIATED WITH SELECTED REACTOR SAFETY SYSTEM INTERFACING COMPONENTS OVER A SPECIFIC THREE-YEAR PERIOD PUMPS AND VALVES

REACTOR SAFETY SYSTEM	REACTOR TYPE		
INTERFACING COMPONENT	PWR	BWR	BOTH
REMOTELY OPERATED VALVES (ROV)	10 (54)	8 (61)	18 (115)
MANUAL VALVES (XV)	11 (21)	2 (18)	13 (39)
TOTAL VALVES (ROV + XV)	21 (75)	10 (79)	31 (154)
TOTAL PUMPS	11 (27)	3 (27)	14 (54)

( ) = UPDATED FROM LER ANALYSIS

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Exhibit 2.5

INITIAL QUANTIFICATION OF HUMAN ERROR FOR PUMPS AND VALVES EXAMPLE OF RESULTS

REACTOR SAFETY SYSTEM INTERFACING COMPONENT	REACTOR TYPE		BOTH
	PWR	BWR	
REMOTELY OPERATED VALVES (ROV)	0.3×10^{-3} (1.8×10^{-3})	0.6×10^{-3} (4.2×10^{-3})	0.4×10^{-3} (2.8×10^{-3})
MANUAL VALVES (XV)	1.5×10^{-3} (2.8×10^{-3})	1.4×10^{-3} (12.6×10^{-3})	1.5×10^{-3} (4.4×10^{-3})
PUMPS	1.2×10^{-3} (2.9×10^{-3})	0.6×10^{-3} (5.3×10^{-3})	1.0×10^{-3} (3.7×10^{-3})

( ) = UPDATED FROM LER ANALYSIS

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Canadian Experience with Human Error or Performance Degradation

No numerically analyzable data were available to the authors for statistically or systematically assessing the rate or causes of human error in the operation and maintenance of CANDU reactors. To the best of our knowledge, no such data exist in a readily usable form. However, for the purposes of obtaining some insight into human error and its human factors causes, two sources of information provided a basis for drawing some conclusions. The two sources of information were: (1) a sample of significant event reports for the month of January 1981; and (2) review and discussion of a draft report on abnormal occurrences being prepared by the AECB Orientation Center. Most of the human errors revealed in our brief analysis can be rather easily categorized as human engineering deficiencies, lack of task-specific training, or inadequate procedures, although some are not amenable to this categorization. Also, in general, the errors can be associated with the initiation of a task, with the detection of some off-normal situation, or with recovery from an off-normal situation.

Review of Significant Event Reports (SER's)

Approximately 25 SER's from the month of January 1981 were reviewed for the Bruce and Pickering nuclear generating stations. In general these reports tended to be sequential so no bias in the sample is apparent in their selection. No attempt has been made to analyze either the cause or the consequences of these events. They have been reviewed to develop a general impression of the types of human error that are typical in a CANDU station's operation. No specific plants or events or systems are identified. Rather, a brief statement of the human factors issue is listed below in order to share our impressions with the reader.

- Handswitches or valves are inadvertently left in the wrong positions--usually after some test. These errors are typically not detected for many hours going across one or more shifts.
- Improper or poor work practices were used during maintenance. This includes poor planning, trial and error, and no proper work authorization.
- Inadequate communication between control room operators and assistant operators in the plant.
- Procedures which were unavailable, inaccurate, or did not exist for the particular situation. This includes out of date drawings.
- There was an apparent lack of job-specific training for a task. Related to this was the failure to coordinate with a more knowledgeable person before proceeding.
- Annunciators went undetected apparently because the large number of insignificant annunciators reduced the probability of detection or the motivation of the operator to search for the significant annunciator message.
- Incidents occurring on one shift were not identified during shift turnover and sometimes extended to more than one shift.
- Faulty or confusing labeling led to mis-identification of components.
- Instrumentation was questionable, difficult to interpret, or out of calibration.

AECB Draft Report on Abnormal Occurrences

This report, dated February 1982, presents a description of selected events highlighting the safety significance and remedial measures that should be or are taken to minimize the probability of recurrence. The criteria for selection of the nine events discussed is generally such that they are serious events and do include procedural deficiencies and inadvertent human errors. In our judgment human factors issues are involved in six of the nine reported events. These are summarized below.

- An inoperable valve had no readily apparent status indication.
- No specific operating procedures were available for reconfiguring the system after inadvertent loss of major core cooling water source and primary cooling pumps.
- Automatic initiation of crash/cool-down was blocked due to operator error which left handswitches for all three channels in the wrong position. No specific annunciation or alarm was available to the operator.
- The closed position of an isolation valve in the ECCS was not registered and attempts to open the valve manually were impeded by the absence of operating procedures and up-to-date drawings.
- A major D_2O spill occurred due to failure of the operator to empty the storage tank prior to transferring the primary coolant as required in the operating procedure.

- A total loss of AC power occurred when one diesel generator was isolated and the other erroneously selected in an "off" position. Due to a common "not on auto" annunciation for both diesel generators, the switch selection error went undetected by the operator for three shifts.

SECTION 3

THE STATUS OF HUMAN FACTORS IN THE NUCLEAR POWER INDUSTRY AND THE ATOMIC ENERGY CONTROL BOARD

During the brief course of this study, we were able to interview most all of AECB's senior managers; to read numerous Board papers, reports, and regulatory documents; to visit a four-unit CANDU control room and a training simulator; and to meet with two industry human factors specialists, a simulator instructor, and two control room operators. From these information sources--limited as they were--we attempted to assess the status of human factors in the Canadian nuclear industry and the Canadian Atomic Energy Control Board. Our conclusions are presented here.

Recognition of the Importance of Human Error and its Prevention

Many published AECB papers demonstrate that for some time the Board has been keenly aware of the relations between human error and plant safety. In one paper the Board's President (Jennekens, 1979) said, "Simply stated, the defence-in-depth concept means that the probability of operator error and system failure must be minimized." In another paper (Jennekens, 1977) he also said, "Avoidance of human errors has proven to be an extremely important part of the Canadian safety philosophy." Other statements made by both the AECB and industry staff that we interviewed reiterate a general recognition of and concern with human error.

Identification of Needs

Many AECB papers and staff comments also contain recommendations or proposals for activities that would prevent or minimize human error. For example, Pannell and Campbell (1980) in a review of the Three Mile Island accident and its implications for CANDU safety recommended that licensees or the AECB review and improve (1) control room instrumentation, (2) operating and maintenance procedures, (3) training programs, (4) control room staffing requirements and facilities, and (5) the use of simulators. They conclude by further proposing that "AECB should undertake an investigation of the means whereby the potential for and effects of human error in the operation of nuclear power plants under normal and emergency conditions can be effectively studied."

Understanding of the Appropriate Technology

While we found that both the Board and industry recognize the importance of human error to plant safety and have proposed actions to prevent it, there is no consensus as to what should be done, how it should be done, or who should do it. For example, while provision has been made for including "the operator" in safety design matrices, the method for dealing with this element of the analysis appears to be less well-understood and developed than that for dealing with the responses of the process or safety systems to failure. One AECB staff member said, "We really don't know how to treat the operator in these matrices."

Familiarity with the human factors technology ordinarily used in the United States and Europe to minimize human error seemed to be generally lacking, particularly among certain Board staff members. We also observed that in the AECB there is an incomplete understanding and agreement on what is meant by human factors or human factors technology. Some Board staff members properly identified it as an interdisciplinary field combining industrial engineering with psychology and ergonomics. On the other hand, some spoke of human factors as if it were a branch of sociology, a school of philosophy, or simply "common sense." Still others believed it was an intractable problem.

On the other hand, the Canadian nuclear power industry, at least as far as we can infer from discussions with Ontario Hydro representatives, has had human factors staff and a human factors program for some time. We have no basis on which to judge its capability, its contributions to operability and safety, or the degree of its acceptance by utility management.

Implementation of a Human Factors Program

Given the lack of consensus among Board staff as to what human factors technology is or whether and how it should be used to reduce the probability of human error, it is not surprising that AECB has no policy nor systematic program for the human factors review of new plant designs or the operation and maintenance of licensed plants. Nor does it systematically evaluate personnel selection, training, procedures, or job aids as these have been developed by the nuclear industry. While our information is more limited, we infer that the nuclear industry

also does not have an integrated human factors program. In both the AECB and industry some of the elements of a human factors program do exist; some have been proposed; others have not yet been considered.

Exhibit 3.1 summarizes our assessment of the status of human factors technology in the Canadian nuclear power industry (top half of the exhibit) and in the AECB (bottom half of the exhibit).

Columns of Exhibit 3.1 identify the major elements of human factors programs as they typically exist in the development and regulation of many complex man-machine systems. Rows in this exhibit indicate the activities associated with each of these program elements. Cell entries containing an "A" indicate the existence of some program activity. Cells containing an "R" represent a program activity identified as being needed in a published AECB paper. Cells containing a "P" denote activities identified by AECB staff as being needed during our interviews. Thus, for example, we found that industry has designed, developed, and has had in operational use for some time an extensive operator training program. However, at AECB we learned that there was some concern about whether or not the content of this training program was derived from a complete description of the skill and knowledge requirements of each operator job and whether or not it might contain content that has not been demonstrated to be job relevant. Recommendations and proposals have been made for both the industry and the Board to devote more attention to the review and evaluation of the entire training issue.

Exhibit 3.1
Status of Human Factors in the Industry and the AECB

		Functions & Task Analysis	Qualitative & Quantitative Personnel Needs	Personnel Selection	Personnel Training & Simulator Use	Personnel Testing & Certification	Control Room Human Engineering	Maintenance Design	Procedures and Job Aids	Event Reporting
NUCLEAR POWER INDUSTRY	Analysis and Research				R ?		?			?
	Design, Development, and Implementation				A		A			A
	Evaluation				? R		A R	R	R	?
	Operational Use				A		A			A
ATOMIC ENERGY CONTROL BOARD	Regulatory Research	P			P	P,R A	P,R	P		R
	Regulatory Development	P			R		P	P		
	Review and Approval	P	R		R	R	P ?	P		
	Inspection and Audit or Test					A	P			

Legend:

A = Activity underway
? = Activity may be underway
R = Activity recommended in AECB published paper
P = Activity proposed by one or more AECB staff interviews

A similar concern was expressed in the area of operator examinations. Given AECB's limited resources the current operator examination system appears to be a well-thought-out one, although the examination program's management indicated that attention is being given to possible changes in several areas. An area for consideration entails the substitution of multiple-choice examination items which do not invite the examinee to provide an essay response. Essay responses tend to evaluate the examinee's expository skills as well as job knowledges. Another area for consideration involves an analysis of the statistical validity and reliability of examination items. This can best be done when a multiple-choice examination format is used.

Although the industry has for some years had a human factors capability associated with its control room design and development activity, operator input to the control room design process is a recent and laudable improvement. We could not determine whether industry has undertaken analysis or research on control room human engineering or determine what methods it uses, if any, to evaluate the relation between control room human engineering and operator error. On the AECB side we learned that considerable discussion had been given to the desirability of conducting some form of review and evaluation of control rooms. We understand that no specific plans have been made or evaluation tools developed for this purpose. Similar discussion has been given to a comparable review and evaluation of the human factors design for plant maintenance and several proposals for maintenance reviews were mentioned during our interviews with Board staff.

On significant event reporting we obtained copies of a human error reporting form developed by Ontario Hydro. We are

not aware of the nature or extent of the analysis and research that went into the development of this form nor of any effort to evaluate it as a means for collecting human error data. One Board report recommended that AECB pay more attention to human error, its causes, and relation to plant risk.

Task analysis information provides the technical basis for determining the number and types of personnel needed for staffing, the requirements for the selection of personnel, the content of training, procedures, and job aids, and is the basis for a sound review of control room and maintenance human engineering design. We learned that while there has been some discussion of the desirability of a functions and task analysis of the activities of operator personnel, no such task analysis information exists today to AECB's knowledge. The lack of such information leaves both the industry and AECB in a weak position to defend or to evaluate the functioning and effectiveness of man in relation to the plant and to plant safety.

SECTION 4

HUMAN FACTORS GOALS RELATED TO NUCLEAR POWER PLANT SAFETY

The primary objective of a human factors program is to minimize the opportunities for human error in plant operation and maintenance that have safety consequences for plant personnel and the public. Responsibility for achieving this objective is shared by the industry and AECB. In order to achieve this objective, it is necessary to meet the following goals:

- Develop and maintain an up-to-date description of the functions and tasks required of plant personnel.
- Identify the numbers, types, and work arrangements of personnel required to operate and maintain plants.
- Accurately select from among job applicants candidates with the aptitudes, prior experiences, and personality characteristics necessary to be reliable employees.
- Provide trainees with cost-effective, job-specific training exercises, materials, and devices needed to impart job skills and knowledges.
- Use objective, bias-free tests for licensing personnel and for the periodic re-testing of personnel qualifications.
- Design and layout the work environment and man/machine interface in the control room to support required human performance and minimize human error.
- Design and layout the work environment and man/machine interfaces of the plant facility and equipment to support maintenance performance and minimize human error.

- Develop and validate normal and emergency operational and maintenance procedures and operator aids that are technically accurate and optimally comprehensible.
- Develop and use a significant event reporting system to permit the compilation and subsequent analysis of records of human error by type, probable cause, and potential consequence.

Exhibit 4.1 shows these goals in relation to the nuclear power industry and the AECB and indicates in each cell an area of need (N) in which some action should be taken either to verify the existence of that need or to develop a means for meeting that need. Cells which contain an $\bar{N}$ represent areas where we recommend a program and where activity has also been recommended by AECB in a published paper or during our interview meetings.

Goal: The Development of a Functions and Task Analysis Data Base for Jobs to Which Plant Safety is Sensitive

Fundamental to any effort to improve or evaluate the operational safety of any plant is the need for a complete and accurate description of the tasks required for those workers to which the plant is safety-sensitive. This includes, at the least, control room personnel. Such a description of tasks is called a Functions and Task Analysis. Methods for developing and using a task analysis data base were developed and used in the early 1950s, first for military systems and subsequently for other major non-military systems.

A task analysis data base ordinarily provides a complete, formatted, and computer-searchable description of the activities of each key worker in each operational sequence determined by

Exhibit 4.1
Human Factors Goals For the Industry and the AECB

		Functions & Task Analysis	Qualitative & Quantitative Personnel Needs	Personnel Selection	Personnel Training & Simulator Use	Personnel Testing & Certification	Control Room Human Engineering	Maintenance Design	Procedures and Job Aids	Event Reporting
NUCLEAR POWER INDUSTRY	Analysis and Research	N		N	$\overline{N}$		N	N	N	N
	Design, Development, and Implementation	N			N		N	N	N	
	Evaluation		N	N	$\overline{N}$		$\overline{N}$	$\overline{N}$	$\overline{N}$	N
	Operational Use			N	N		N	N	N	
ATOMIC ENERGY CONTROL BOARD	Regulatory Research	$\overline{N}$			$\overline{N}$	$\overline{N}$	$\overline{N}$	$\overline{N}$	N	$\overline{N}$
	Regulatory Development	$\overline{N}$			$\overline{N}$		$\overline{N}$	$\overline{N}$		
	Review and Approval	$\overline{N}$	$\overline{N}$	N	$\overline{N}$	$\overline{N}$	$\overline{N}$	$\overline{N}$	N	
	Inspection and Audit or Test					$\overline{N}$	$\overline{N}$	N		

LEGEND

N = AREA OF NEED

$\overline{N}$ = AREA OF PROGRAM NEED IDENTIFIED IN PUBLISHED AECB PAPER OR PROPOSED BY ONE OR MORE BOARD STAFF IN INTERVIEW

engineering and risk assessments to be critical to plant productivity and safety. Exhibit 4.2 is an example of a format being developed for the U.S. Nuclear Regulatory Commission as the operator task analysis data base for U.S. nuclear power plants. A data base containing items of information such as these, in addition to the skills and knowledges required to perform each task, provides the technical basis for:

- Developing the content of training courses
- Identifying the educational qualifications of personnel
- Establishing staffing requirements
- Identifying candidate items for inclusion in a valid licensing examination
- Evaluating the human engineering design and layout of control rooms
- Identifying requirements for an evaluating operational aids
- Identifying the essential content and evaluating operational and emergency procedures.

A task analysis is analogous to a computer program. Without it, there is little basis other than hunch or speculation for determining what performance is required of man, what knowledges and skills are necessary for that performance, and how that performance interfaces with emergency and the balance of plant systems.

EXHIBIT 4 2
TASK DATA FORM (1) *DESCRIPTIVE*

PLANT IDENTIFICATION

Plant Name: LIMERICK CR Type: SINGLE NSSS Type: GE - BWR A E: BECHTEL

TASK IDENTIFICATION

Operating Sequence: STATION BLACKOUT

Operator Function/Sub-function: Supervise & Control/Mitigate Consequences of Accident

Task Statement: Respond to Incoming Alarms

Task Purpose: Cue: Annunciators

Comments: Operating Crew Will Also Observe Other Incoming Alarms

Operating Sequence ID:

Task Sequence No.: 1 (Tentative)

INPO Code:

Task Frequency:

Task Duration:

Procedures:

JPA's:

DESCRIPTION OF TASK ACTION

Who Does Subtask	Location of Action	Behavioral Element (action)			Object of Action				Means of Action	Communication Link		
JOBCAT	LOC	BSEQ	ITER	VERB	COMPONENT	PARAMETER	PLANT SYSTEM	INPO EQUIV	MEANS	RESPONDENT	RLOC	CONTENT
RO	CR			Observes		Trip	Reactor	12	Annunciators			
RO	CR			Observes		Trip	Turbine C.	48	Annunciators			
RO	CR			Observes		Isolation	Main Steam	105	Annunciators			
RO	Reactor Control Console			Acknowledges			Annunciator		Discrete Controls			
RO	Reactor Control Console			Informs					Verbal	SRO	CR	Rx & Turbine Trip, MS Isolation

Goal: The Identification of the Staffing and Organizational Factors and Work Structure Characteristics of Personnel Required to Operate and Maintain Plants

Staffing and work structure demands are driven by the requirements of safety standards, operational quality assurance, maintenance effectiveness, and effective management for normal, off-normal, and emergency conditions. Human factors considerations in this area are generally "non-hardware oriented" and focus on manpower and personnel policies that impact organizational effectiveness, shift manning, and other factors that affect job satisfaction.

Staffing and Organizational Factors

A coherent organization and appropriate management and technical staffing are necessary for the utility to conduct safe nuclear power plant operations and all required plant maintenance. In addition, both management and technical plans must be available for accident mitigation, including all long-term efforts required to return the plant to normal conditions in the event of an accident.

Work Structure Factors

Research over many years in settings comparable to the nuclear industry demonstrates that an effectively organized and positively perceived work structure is correlated with organizational effectiveness, productivity, and safety. Work structure refers to the way in which work is organized, staffed, managed, supervised, evaluated, and rewarded. A particularly important area related to safety in commercial power plant operations is concerned with all of the factors of shift work including duration, rotation, and other factors in full operational manning, 24 hours a day, seven days a week. In brief,

shift staffing must be designed such that operational personnel are not only competent technically but are also fully alert to indications of changing conditions that may be symptomatic of pre-accident states.

Goal: The Development of a Personnel Selection Test that Predicts Effective, Safe Personnel Performance

It is well established that individuals with certain characteristics (e.g., personality, education, work experience, attitude, etc.) perform more effectively and with fewer errors and slips in a job than others. This general knowledge has been translated into techniques for developing and validating personnel selection tests that predict with a high degree of accuracy which candidates for a job are more likely to perform better than others. Valid and reliable selection tests have for years been used in the selection of commercial aircraft pilots, computer programmers, and other civilian and military personnel.

It is particularly important to the nuclear industry to select individuals likely to perform tasks safely and effectively. Mistakes in selection can be costly not only in terms of the expense of the recruitment and hiring process but also in terms of the consequences of an improper personnel choice on plant safety and damage control.

The usual method for the development of a sound personnel selection instrument or battery of tests consists of starting with many items judged from a task analysis to be related to job performance. These are then incorporated into a provisional instrument which is used to appraise current staff. The correlation of each candidate item in this provisional selection

battery with other measures of personnel performance (e.g., supervisor and peer ratings, etc.) is then computed. Items with low correlations are eliminated. Those with high predictive validity and reliability are retained for construction of a final selection instrument or battery. As the selection instrument is used for personnel selection, data accumulate on the success and failure of individual items to predict performance. Periodically this item pool is analyzed to ensure that the selection technique is effective.

Goal: The Ability to Provide Trainees with Cost-Effective Job-Specific Training Exercises, Materials, and Devices to Impart Job Skills and Knowledges

The lack of proper training has been repeatedly pinpointed as a major cause of human error in the nuclear industry and elsewhere. The Three Mile Island accident is but one example of inadequate training. However, given the Canadian regulatory philosophy, it is our opinion that the AECB's interests lie rather more with the product of training, namely an effective operator, than with the process used to produce that product. This position is consistent with several AECB published papers and comments made in interviews that suggest that AECB review training methods, content, and the use of simulators. We understand, for example, that the AECB Operator Certification Program has, among its responsibilities, the assessment of utility training programs. If this is indeed the case, then in our opinion the AECB should have a method that permits it to systematically relate the content of utility training with the content of certification examinations to ensure that the two are congruent and that both relate to the skill, knowledge,

and performance requirements of operators during normal and emergency conditions. To our knowledge such an evaluation method does not now exist.

Goal: The Development of a Reliable and Valid Examination for the Certification and Re-Qualification of Operators

To assure that the operating personnel of nuclear operating stations are qualified to operate their stations safely, the AECB prepares, administers, and scores the performance of shift supervisor and control room operator candidates on a two-part written examination. The examination covers the theoretical and practical aspects of all station systems and operations.

Our impression of this examination system and of the examination content is that it is a carefully planned and implemented program being carried out by experienced subject matter experts. However, in our review of this program, and in our discussion with its principal staff, we conclude that it could be improved in several ways to increase the validity and reliability of the examinations process in predicting which operator candidates are qualified. Combined with a similarly valid and reliable trainee candidate selection test (discussed earlier), an improved certification examination should increase the confidence of both the industry and the Board in the licensing process and in the performance of licensed operators. If, in addition, licensed operators are periodically re-examined to determine that they have both retained learned skills and knowledges and have also acquired new skills and knowledges required by improvements in plant operation, confidence in the licensing process and ultimately in plant safety should be further increased.

One characteristic of a valid and reliable examination is that all examination items test for the presence of skills and knowledges that have been determined by a task analysis to be an essential and important part of job performance. It is not enough to believe that an operator ought to possess a skill or have a knowledge of a system or concept to include it on an examination. Too many examinations fail to contain job-relevant items and therefore fail to accurately predict operator qualifications. The best--perhaps only--way to ensure that this is done is to base item selection on a task analysis.

Another characteristic of a valid examination is that it does not inadvertently invite the examinee to display skills or knowledges that are necessary to pass the examination but that are not necessary to perform the job. The present examination format may unintentionally invite the examinee to demonstrate expository skills which are questionable as a requirement of the operator's job. This is recognized by the certification program staff and we understand that some effort has been made to experiment with multiple-choice test items that do not require a high degree of expository skill and that eliminate the possibility of examiner bias in examination scoring.

A final characteristic of a good examination program is that it periodically re-examines personnel to ensure that they have retained relevant skills and knowledges and learned new ones called for by new technology or operating procedures.

Goal: The Design, Layout, Work Environment, and Man/Machine Interface in the Control Room that Support Required Human Performance and Minimize Human Error

Human error in the performance of required control room tasks can often be traced to improper design that does not accommodate human capabilities and limitations. These "design-induced errors" can be identified through a structured control room design review. Furthermore, such human engineering deficiencies (HED's) that are assessed to be important to safety can be corrected to the application of known human factors engineering principles and criteria. The identification of these human engineering deficiencies and the correction of those related to safety will improve the ability of nuclear power plant control room operators to prevent accidents or cope with accidents if they occur by improving the layout, work environment, and man/machine interfaces of the control room.

Certain designs are known to almost invariably lead to human error through misinterpretation, failure to respond, or incorrect response. For example, there are numerous "population stereotypes," a term used to identify the way in which people in an environment expect things to behave, especially with regard to directional movement. For example, one expects the clockwise turn of a control knob to increase the value of the affected parameter. There are no technical constraints that would prevent sound human engineering design of control rooms for plants currently being designed and built. There are obviously some constraints that make complete conformance to established human engineering design criteria and principles infeasible for currently operating plants. However, a great deal can be done

to identify human engineering deficiencies and to make modifications to existing plants which will effectively eliminate or reduce to a reasonable level the probability of design-induced error.

Goal: The Design, Layout, Work Environment, and Man/Machine Interfaces of Plant Facility and Equipment that Support Maintenance Performance and Minimize Human Error

It is generally known that human error during maintenance and testing activities is the root cause for most events leading to equipment damage, plant unavailability, or accidents threatening to public health and safety. If maintenance personnel cannot easily and accurately locate the desired equipment, if they have difficulty in gaining adequate access to it, if they must search through a poorly prepared technical manual, if they do not have the proper tools and work environment, and if the equipment status is not properly identified both within the plant and in the control room, then degraded maintenance performance can be expected. This can result in lower equipment reliability and greater potential exposure to radiation for longer periods of time than would be otherwise necessary. The likelihood of serious maintenance errors is increased when such activity occurs in the presence of temperature extremes, noise, and inadequate lighting.

The major human factors contribution to better design for maintainability can be affected through (1) better accessibility, identification of equipments, and control of environmental factors, (2) more effective protective garments, tools, and instruments for use during maintenance in a radioactive environment, and (3) better maintenance procedures.

Goal: The Development and Updating of Normal and Emergency Operational Procedures, Maintenance Procedures and Operator Aids that are Technically Accurate and Optimally Comprehensible

The performance effectiveness of many operator and maintenance personnel functions depends on the accessibility, technical accuracy, and comprehensibility of procedures and job aids. Procedures and job aids should be used to achieve personnel performance in those tasks (1) in which training is not the predominant means for achieving performance because the tasks are performed too infrequently or are too complex to learn easily, (2) which require access to considerable numerical data, or (3) which have other characteristics that suggest procedures over training for achieving personnel performance. In order to assure the development of effective procedures and operator aids, several considerations must be accounted for in procedure development and update:

Procedure Preparation Specification

The specification should be for use by the licensee in procuring or developing procedures. This process should incorporate the following features.

Procedure Development Process. This part should describe the development sequence which will ensure complete coverage and technically accurate data. This would include general guidelines for normal and emergency operating, maintenance, and administrative procedures.

Format Requirements. This part should present guidance on presentation alternatives and features which will maximize comprehension and retention by the user. In particular,

alternative choices for information presentation techniques should be identified, formal limitations of CRT and other computer-based displays should be identified, and the feasibility of using CRTs for the presentation of procedures should be addressed.

Performance Verification. This part should address the verification technique necessary to ensure that critical tasks and safety procedures are performed correctly. Both the technical adequacy and the comprehensibility of the task should be substantiated.

Update and Revision. This part should address an effective process for updating and revising operational and maintenance needs. This should include requirements for an information management system that will (1) index and cross-index all plant procedures to ensure timely and appropriate incorporation of changes, (2) track procedures to ensure that they are distributed and recalled in a timely manner and to ensure that operational feedback from within and outside the plant is incorporated into procedure revision when necessary.

Operator Aids Research

In addition to development of a specification procedure, consideration should be given to more advanced operator aids using computer-based information systems and multifunction electronic displays to provide operating personnel with more integrated information. In particular, displays for safety vector status and disturbance analysis system monitoring should be considered for their effectiveness in aiding the operator to detect and mitigate off-normal conditions.

Goal: The Development of an Actuarial Human Factors Data Base

For many years it has been recognized that statistically valid and reliable data on human error is needed for such purposes as probabilistic risk assessment. Several attempts have been made and are being made to assemble this data. The most notable of these attempts is the work of Swain and his colleagues at the Sandia National Laboratory in New Mexico. There are, however, limitations to the value of the Swain human error data. Much of it is subjectively derived. Much was obtained from systems other than nuclear power plants. The range of tasks covered is limited, and error probabilities are not given for tasks performed under stress or for the cognitive tasks which are so important in the successful mitigation of emergencies. In our opinion, the best potential source of actuarial data on human error is that of a properly designed and used significant event reporting system. We understand that the Canadian industry is making an attempt to develop such a reporting system, and we have examined a copy of a "Human Factors Analysis" reporting form developed by Ontario Hydro. We believe that experience with the use of this form should be evaluated, and an effort to improve it made if necessary. We recommend that an analysis be made of human error data available from the use of this or other forms and that these data be compiled in a form for use in evaluating the effects on performance of control room changes, changes in training, and in conducting probabilistic risk assessments.

SECTION 5

A STRATEGY FOR ACHIEVING THE HUMAN FACTORS PROGRAM GOALS

The human factors goals identified in Section 4 can only be achieved through some strategy which is compatible with the regulatory philosophy of the AECB. In this section of the report we will briefly restate the essentials of the AECB regulatory philosophy and then present a strategy for achieving the goals which is compatible with that philosophy. A long-range plan for implementing this strategy is developed in Section 6.

The AECB Regulatory Philosophy

Our first interview at AECB was with the Board President who explained the regulatory philosophy in some depth. Other key staff personnel also elaborated on the regulatory philosophy. Perhaps the most concise overview of this topic has been provided by Jennekens (1981) in a paper titled "Nuclear Regulation--The Canadian Approach." Jennekens states (page 4):

> The Canadian approach to nuclear regulation has been to establish a set of fundamental principles and basic criteria. The onus is then placed upon the licensee to develop the conceptual and detailed design, method of operation of a proposed facility, and to demonstrate that the facility will be operated with a high standard of public and occupational health and safety, security, and environmental control.

In the same paper Jennekens also presents several fundamental principles (page 2):

a. Primary responsibility for achieving high standards of nuclear safety and environmental protection in the design, construction, commissioning, and operation of nuclear facilities resides with the licensee.

b. The credibility of the nuclear regulatory process depends not only upon its technical correctness and practicability, but also upon acceptance by the public-at-large of its perceived effectiveness and efficiency.

c. Regulatory criteria and principles should be concise, clearly stated, and understandable.

d. Regulatory decisionmaking should be based upon stated criteria and principles taking into account pertinent scientific and technical facts only.

e. Fairness and impartiality must characterize all regulatory decisionmaking.

f. The regulatory process should be subject to a comprehensive periodic review and evaluation to ensure that it continues to produce the desired results at justified costs.

Concomitant with the regulatory philosophy is the essential safety philosophy of the "defence-in-depth" concept. This concept is stressed in papers by Jennekens (1980), Atchison (1979), and Domaratzki (1981). The first two papers stressed the importance of the human element in the defence-in-depth concept as indicated following.

Jennekens. "Simply stated, the defence-in-depth concept means that several independent measures must be taken to minimize the probability and consequences of human error and system failure." He then lists seven factors which are important in the defence-in-depth concepts and notes that "A quick review of each of the seven examples of the application of the defence-in-depth concept will reveal that there is a common element--and that of course is the human element."

Atchison. "Application of the defence-in-depth approach is based first on minimization of the probability of human and equipment failures and secondly on the provision of highly reliable protecton systems, just in case these failures occur anyway."

A Strategy for Incorporating Human Factors in the Licensing Processes

A strategy can be developed for achieving the human factors goals identified earlier which is quite compatible with the current AECB regulatory philosophy. In general this means leaving the responsibility for incorporating human factors in the design and development of nuclear power plants with the licensee while at the same time assuring that the AECB has appropriate criteria and competent personnel to assess the application of those criteria to the human factors designs and plans of the industry. The overall strategy requires policy decisions in four areas:

1. Organizational changes
2. Development and application of human factors criteria
3. Conduct of audits and inspections
4. Implementation of a long-range plan.

Organizational Changes

A fundamental principle of the Canadian regulatory process is that it be credible. As Jennekens stated (1981), "Both technical and administrative competence are essential prerequisites when considering regulatory credibility. The competence in human factors necessary to carry out the strategy being discussed and the plan recommended in Section 6 of this report will require two types of human factors professionals: a human factors

engineer, and a personnel and training psychologist. Both individuals should have experience in working with complex systems and engineering personnel and have achieved recognition by their peers in the human factors profession. Suggested qualifications for these personnel are contained in Appendix 1. The human factors professionals should be integrated into the present AECB structure. No special human factors organizational element is considered necessary. The human factors engineer should be part of the Safety Evaluation Division and the personnel and training psychologist should be part of the Operator Certification and Research Facility Division.

Development and Application of Human Factors Criteria

The availability of unambiguous and concise criteria that can be consistently applied is an essential part of the current regulatory philosophy. Not all human factors considerations can be expressed as quantitative criteria, but there are a wealth of acceptable design practices, guidelines, and standards that can be interpreted by competent human factors professionals. We are unaware of any human factors criteria specifically developed for Canadian nuclear power plants, but there are many such criteria documents (i.e., standards, guidelines, practices) used by the United States Nuclear Regulatory Commission and the nuclear industry. Appendix 2 is a partial listing of some of these criteria documents that might be adapted for use by the AECB.

Conduct of Audits and Inspections

The conduct of reviews, audits, and inspections is an integral part of the licensing process described by Joyce (1979) and the continuing compliance process described by Domaratzki

(1979). Human factors should be specifically identified in the licensing process particularly during the construction approval phase and the operating license approval phase. During the construction approval phase, human factors activities should include:

- Agreement on relevant human factors criteria
- Review of designs of facilities, equipment, and the control room to minimize design-induced errors
- Review of the staffing and training program
- Review and acceptance of the safety report for human factors issues.

During the operating license approval phase, human factors activities should consist of review of emergency operating procedures, detailed designs of man/machine interfaces, the certification of operating personnel, and the safety report. A human factors audit of the control room should be made during this phase when design and construction is complete enough to permit assessment of the man/machine interfaces and task demands in the control room. During the operational phase, human factors personnel should review safety event reports for those with human factors significance and then possibly conduct on-site inspections as warranted.

Implementation of a Long-Range Human Factors Plan

The final policy decision area focuses on the implementation of a long-range human factors plan as described in Section 6 of this report. This plan together with the changes required by the policy areas just discussed provide the basis for achieving the human factors goals identified in Section 4.

SECTION 6

RECOMMENDATIONS FOR A LONG-RANGE HUMAN FACTORS PLAN

This section contains recommendations for effecting the strategy described in Section 5 and achieving the goals identified in Section 4. A separate program was identified for the strategy implementation and for each of the nine human factors goals. Each program recommendation is organized in terms of a technical requirement, importance, schedule, implementation steps, dependencies, and resources.

Evaluations of the relative importance of technical requirements were derived from a consideration of safety system needs, programs already in existence or planned, and the judgment of the authors based on experience with similar types of problems and requirements in the U.S. power industry and in other complex systems. One of three levels of relative importance--high, medium, or low--was assigned to each technical requirement. Medium or low should not be interpreted as meaning unimportant; each technical requirement is important.

Recommended scheduling information is provided in terms of urgency and duration. Four categories of urgency were used to indicate that actions should be started immediately, within 1 to 2 years, within 3 to 5 years, or within 6 to 10 years. Evaluations of urgency were made separately from evaluations of importance. Some actions of high importance are of low urgency because they are dependent upon completion of prerequisite actions. Most of the recommendations that have a high degree of urgency were assigned to the 1 to 2 year category. A few recommendations, including those that are mostly policy decisions, are assigned to the immediate category. The authors

believe that these are of such high importance and urgency as to warrant extraordinary management actions to expedite their implementation.

Implementation presents the steps required to meet each goal and, where necessary, any special scheduling considerations. Dependencies are noted for recommended actions that are either contingent upon results from some other program or interact with other requirements.

Finally, resources are estimated in terms of the professional man-years required, special scientific/technical skills, and unique facilities or equipment.

At the end of this section, a chart (Exhibit 6.1) has been developed which shows a schedule for meeting the recommended plan. Each technical requirement is identified and the approximate start time and duration is indicated.

Strategy Policy Implementation

This recommendation is based on effecting the policy actions required to enable the strategy discussed in Section 5--A Strategy for Achieving the Human Factors Program Goals.

Technical Requirement

The technical requirement is to adopt policies to enable the strategy to effectively incorporate inplementation of a human factors program plan into the AECB licensing process.

Importance

High.

Schedule

Urgency: Immediately.

Duration: 6 months to 1 year.

Implementation

Four steps which parallel the policy requirements which must be developed and adopted as defined in Section 5 are required for implementation.

Step 1: Organizational Changes. It is recommended that a human factors engineer and a personnel and training psychologist be hired as soon as possible and be integrated into the Safety Evaluation Division, and the Operator Certification and Research Facility Division, respectively.

Step 2: Development and Application of Human Factors Criteria. It is recommended that human factors criteria documents (i.e., standards, guidelines, accepted practices) be reviewed and scheduled for adoption as appropriate to the overall program plan which will be implemented by the AECB.

Step 3: Conduct of Reviews, Audits, and Inspections. It is recommended that the licensing process be reviewed to determine the appropriate points for incorporating human factors reviews during all phases of the project. It is further recommended that a limited number of human engineering audits of control rooms be conducted immediately as described under the recommendation later titled "Control Room Human Engineering."

Step 4: Implementation of a Long-Range Plan. It is recommended that the long-range plan for achieving the goals described in the remainder of this section be adopted and implemented as discussed in each separate subsection to follow.

Dependencies

None.

Resources

No resources are required to adopt the policies recommended above in principle. Approximately 3 man-months of a human factors professional would be required to implement Step 2. No other unique facilities or equipment are necessary for this program item.

Functions and Task Analysis

This recommendation is based on achieving the goal described in Section 4.1--The Development of a Functions and Task Analysis for Jobs to Which Plant Safety is Sensitive.

Technical Requirement

A Task Analysis is a sequential description of the interaction between a person and a system. It indicates what information an operator needs to interact with a system under normal and off-normal conditions, the actions he takes to obtain this information and to make control actions, and the purpose of these information-seeking and control activities in relation to plant systems under a range of operating conditions. In our opinion, a Task Analysis provides the necessary technical basis for the design and evaluation of control rooms, procedures, operator aids, personnel requirements, the content of training and licensing examinations, the analysis of communications equipment, and the identification of personnel selection criteria.

Importance

High.

Schedule

Urgency: 1 to 2 years.

Duration: 2 to 3 years.

Implementation

Step 1: Select Operational Sequences. Three variables affect the content of task performance data: control room crewmembers, plant design, and operating sequences. The first

step is to select the operating sequences for which task data will be developed. The criteria to be used for this selection will include the criticality of the sequence for plant safety as determined by probabilistic risk assessments, the frequency of occurrence of the sequence, and the extent of operator involvement in the sequence. If there is no involvement, then that sequence is obviously not selected for task analysis.

Step 2: Develop a Plan for Task Analysis Data Collection. This step calls for the design of the basic task analysis data format (a sample of part of a format is presented earlier in this report); the development of data collection procedures, the collection of the task data, and the entry of the data into a data management system for subsequent use.

Step 3: Desk-Top Task Analysis. A substantial portion of a task analysis can be done with plant documentation (e.g., operating manuals, system descriptions, etc.). Ordinarily, all of the major tasks required by each operator in each operating sequence can be identified by task title prior to field data collection in a plant.

Step 4: Field Data Collection. When the desk-top analysis has been completed, the data collection team obtains additional data available from operators, procedures manuals, and from walk-throughs and talk-throughs of the operating sequences. Videotapes of the walk-throughs of sequences provide a valuable data source for final completion of the task analysis data. A controlled vocabulary and structured sentence format assures that task data are recorded in a consistent and usable manner.

Step 5: Data Base Use. When the task analysis has been completed for all key operator tasks and operating sequences--including the tasks of communication within the control room and between the control room and other parts of the plant involved in emergency management, maintenance, and logistics--the data are entered into a data management system. Access to the data base can be shared by the AECB and industry and used as the basis for both human design and evaluation.

Dependencies

No other dependencies are necessary to initiate this program.

Resources

Human factors professionals: 1/12 PMY Step 1; 1/4 PMY Step 2; 1/4 PMY Step 3; 1 PMY Step 4. Reactor design/operations professional: 1/12 PMY Step 1; 1/2 PMY Step 2; 1/2 PMY Step 3; 1 PMY Step 4. Computer programmer: 1 PMY Step 5. These estimates are based on the development of a task analysis for one plant, for 10 critical operating sequences, and for all licensed control room personnel.

Qualitative and Quantitative Personnel Needs

This recommendation is based on achieving the goal described in Section 4.2--The Identification of the Staffing and Organizational Factors and Work Structure Characteristics of Personnel Required to Operate and Maintain Plants.

Technical Requirement

The technical requirement is to ensure the proper organization, numbers, and types of management and technical personnel together with the proper design of shift manning to effectively operate and maintain the plant. In addition, high job satisfaction and minimum personnel turnover should be a related requirement.

Importance

Medium to low, depending upon shortages of trained operators.

Schedule

Urgency: 3 to 5 years.

Duration: 3 years.

Implementation

Two steps are suggested to achieve a goal of adequate qualitative and quantitative personnel requirements in nuclear power plants. Each step is identified below together with the years after start when the principle effort for the steps should occur.

Step 1: Establish Minimal Guidance for Work Structure Factors. Most of the important work structure factors could be determined and documented in terms of suggested guidance rather easily utilizing the approach to follow. First, review the scientific literature on work structure in related process systems; second, survey current nuclear power plant operators to identify work structure factors important to them; and third, review and modify current utility practices as they relate to work structure factors. Data from these efforts should result in sound recommended practices, particularly with respect to shift work and such features as length of workday and duty period, maximum continuous work period, minimum break between work periods, maximum work hours per week or month, etc.

Step 2: Develop Guidelines for the Optimum Staffing and Qualifications for Personnel On Duty at Various Unit Configurations (e.g., Dual Unit Versus Four Unit Shared Control Room Configurations). This step will require the use of job or task analysis data in order to derive the optimum number of personnel required to handle off-normal and accident situations. Consideration should also be given to the location of additional personnel expected during accident mitigation and follow-through to ensure that control rooms do not become overly crowded. It is suggested that rather general guidelines can be promulgated by the AECB and utilities can prepare staffing plans for normal and emergency operations in response to these guidelines.

Dependencies

For the most accurate determination a control room operator task analysis will be necessary prior to the initiation of Step 2. However, past experience will provide a basis for staffing decisions.

Resources

Step 1 would require 1 1/2 PMY--at least one-half of which should be a human factors professional. Step 2 should require 1 PMY with about 50 percent participation by an industrial/ organizational psychologist and the other 50 percent an AECB staff member experienced in related licensing issues.

Training Evaluation

This recommendation is based on achieving the goal of a training program that is compatible with the content of the operator certification examination and with the job performances, skills, and knowledges required of the operator.

Technical Requirement

The technical requirement is to use task analysis or similar data in lieu of it (e.g., operational and emergency procedures) to determine the relevance of the content of the training program and of the certification examination with job requirements.

Importance

Medium.

Schedule

Urgency: 1 to 2 years.

Duration: 1 year.

Implementation

To improve the correlation between training program content and certification examination content, the following steps are in order.

Step 1: Match Current Training Content with Examinations Content. This matching process will pinpoint any existing discrepancies between the two that can be reconciled by mutual AECB-industry agreements. It does not necessarily ensure that either or both are correlated to the operator's job.

Step 2: Match Task Analysis Information with Common Training and Examinations Content. Task analysis information, or if it has not been developed, other task data such as procedures, is then matched with the core content of the training program and certification examination, and the latter are adjusted so that required job performances, skills, and knowledges are represented in both. This step ensures that job content, training content, and certification examination content are all correlated.

Dependencies

The performance of Step 2 is dependent upon a task analysis data base.

Resources

Human factors professional: 1/4 PMY Step 1; 1/4 PMY Step 2. Training professional: 1/4 PMY Step 1; and 1/4 PMY Step 2. Certification and licensing personnel: 1/4 PMY Step 1; 1/4 PMY Step 2.

Personnel Selection Test

This recommendation is based on the achievement of the goal described in Section 4.3--The Development of a Personnel Selection Test that Predicts Effective, Safe Personnel Performance.

Technical Requirement

The technical requirement is to ensure that the personnel selected for positions of critical importance to plant safety, such as control room operators, are chosen based on attributes that have been established as being successful, statistical predictors of safe performance.

Importance

Medium to low, depending upon industry experience and success in selecting safe operators.

Schedule

Urgency: 3 to 5 years.

Duration: 1 year to develop; 3 to 5 years to validate.

Implementation

The following steps are suggested to achieve the goal of the development of a valid personnel selection test.

Step 1: Collect Selection Instrument Item Pool. Personnel specialists, operational, and management personnel are asked to submit candidate items for a selection test based on their judgment of the characteristics of a qualified and safe operator. These may include personality traits, prior experiences,

interests and hobbies, etc., but not the specific skills and knowledges required for specific job training and/or for the certification testing for these jobs. A test specialist then constructs a provisional selection instrument using the proposed items.

Step 2: Initial Selection Test Validation. The provisional selection test is then validated by comparing scores obtained on it by existing employees with other independent measures of the performance of these employees. Items with low predictive validity or low reliability are eliminated; others are retained.

Step 3: Final Validation. As a final step the selection instrument is used as the basis for selecting job candidates, either separately or in combination with other indicators such as biographical data, school grades, training course scores, and the like. Items of low reliability and validity are again eliminated until a desired level of successful prediction is achieved. When this has been done, other more costly or less reliable selection techniques can be reduced.

Dependencies

None.

Resources

Step 1 will require 1/2 PMY of a human factors specialist or psychologist trained in test construction. Step 2 will require 1/2 PMY for item analysis, and Step 3 is estimated to also require 1/2 PMY for final item analysis. Computer support requirements will be required for item by item checking reliability and validity computations and should require approximately 1 PMY of a qualified statistical programmer and analyst.

Certification and Re-Certification Examination

This recommendation is based on achieving the goals of a reliable and valid examination for control room operator certification and re-certification presented in Section 4.5.

Technical Requirement

The technical requirement is to develop an objective, highly reliable, and valid examination for determining that operator candidates are qualified to perform the tasks required of them under all emergency conditions and to use the item pool on which this examination is based to develop a re-certification examination for periodically re-assessing operator qualifications.

Importance

Medium.

Schedule

Urgency: 3 to 5 years.

Duration: 2 years.

Implementation

To improve the validity and objectivity of the existing operator examination and extend it to re-certification examination, the following steps are in order.

Step 1: Validate Examinations Content Against Performance Requirements. Sound examinations technology requires that all items in an examination be derived from the performance required by a job. Expert judgment does not ensure that this is always the case. Task analysis information provides such a basis

since it identifies each task required of an operator under all conditions of operation and the skills and knowledges needed to perform these tasks. Each item used in an examination should, therefore, be linked to the skill or knowledge required by one or more job tasks.

Step 2: Use Objective Examination Items. In order to reduce the possibility that the examination tests for expository skills rather than essential job skills and knowledges, all items on the written examination should be objectively and easily scored items. If, in addition, it is judged that objective items cannot fully tap all of the knowledges required by an operator, consideration should also be given to supplementing on a regular and uniform basis the written examination with a standard oral examination or simulator test. The statistical validity and reliability of the objective items should then be determined over a period of use in order to establish a "bank" or pool of re-usable items.

Step 3: Extend Examination to Cover Periodic Re-Certification. In order to ensure that operators do not become obsolete in essential jobs, knowledges, and skills, the written examination should be re-administered to all operators after some interval determined to be appropriate by the Board and the industry. This step would entail using the pool of validated items to assemble the re-certification examination.

Dependencies

A control room operator task analysis is necessary for Step 1. Neither Steps 2 nor 3 are dependent on prior steps, although Step 3 would require an executive decision by the Board to undertake re-certification.

Resources

Step 1 would require approximately 1/2 PMY of a qualified human factors professional. Step 2 would require 1/4 PMY of a human factors professional and at least 1/2 PMY of a member of the examinations and certification staff or other subject matter experts. Step 3 should require from 1 or 2 professional man-months to assemble a re-certification examination if a pool of validated and reliable examination items exists. This does not include an estimate of the additional resources required to administer and score re-certification examinations.

Control Room Human Engineering

This recommendation is based on achieving the goal described in Section 4.6--The Design, Layout, Work Environment, and Man/Machine Interface in the Control Room that Support Required Human Performance and Minimize Human Error.

Technical Requirement

The technical requirement is to eliminate or minimize design-induced human performance errors through the detection of human engineering deficiencies in the control room, and the application of accepted human factors engineering practices to correct or minimize those deficiencies.

Importance

High.

Schedule

Urgency: 1 to 2 years.

Duration: 3 to 5 years.

Implementation

Four successive steps are considered necessary to implement a feasible approach to achieving properly human engineered control rooms. Each step is identified below together with the years after start when the principal effort for the steps should occur.

Step 1: Perform a Human Engineering Audit of at Least Two Existing (Or About to Be Operational) Control Rooms. At least one of the control rooms selected should be older (approximately 10 years) and another a very recent design. The audit basis can be human factors engineering criteria developed by the U.S. NRC for a similar purpose and documented in NUREG-0700; or, readily available Canadian or U.S. Military human engineering standards and practices for complex system development (e.g., U.S. Military Standard 1472-C). Experienced human factors professionals working with AECB personnel experienced in reactor design and operations can accomplish this effort in the first six months after start.

Step 2: Develop Regulatory Guidance for Control Room Human Engineering. A regulatory guide should be developed to provide guidance to the utilities for reviewing (or designing) control rooms considering good human factors engineering practices. The guidance document can be built upon (1) the experience gained during the control room audits, (2) the adaptation of the U.S. NRC guidelines in NUREG-0700 and any other widely accepted human factors engineering practices in the Canadian Military organization, and (3) the unique requirements of the CANDU reactor as identified by the AECB Technical Staff. This effort can be accomplished within the first year of the total program.

Step 3: Utility-Conducted Control Room Design Reviews (CRDR). This step would require the utility to conduct a CRDR for each of the different control rooms using the guidance developed in Step 2. Each control room review should require no more than six months elapsed time and it is estimated that all control room reviews could be completed during the second to fourth year of the program.

Step 4: Review Utility Reports and Selectively Audit Control Rooms. The final activity to achieving well human engineered control rooms would be a verification of the utilities' effort in performing the control room design review. This can be accomplished by reviewing reports submitted by the utilities or by selectively auditing some control rooms on a scaled-down basis (two or three people for two or three days). The implementation of surface enhancements to control boards in order to correct human engineering deficiencies seems unwarranted for review by AECB. However, those control room modifications which are of a more substantial nature or which affect safety systems directly should be reviewed. The selective audit can account for an unscheduled review of both the method for determining deficiencies and the techniques for correcting deficiencies. This effort can be conducted in the third to fifth year of the program.

Dependencies

A control room operator task analysis would be useful but not necessary prior to the utility CRDR (Step 3). No other dependencies are necessary to initiate this program.

Resources

Human factors professional--1/2 PMY Step 1, 1 PMY Step 2, 1/2 PMY Step 4; reactor design/operations professional--1/2 PMY Step 1, 1/2 PMY Step 2, 1/2 PMY Step 4. The utility CRDR would require an estimated 3 man-months of both a human factors engineer and I&C engineer to perform the CRDR of each unique control room. No other unique facilities or equipment are required for this program.

Design for Maintainability

This recommendation is based on achieving the goal described in Section 4.7--The Design, Layout, Work Environment, and Man-Machine of the Plant Facility and Equipment Support Maintenance Performance and Minimize Human Error.

Technical Requirement

The technical requirement is to minimize design-induced human performance errors in maintenance through the development and application of human factors engineering criteria for the plant facility and equipment.

Importance

Medium.

Schedule

Urgency: 6 to 10 years.

Duration: 4 years.

Implementation

Two separate steps are considered necessary to implement a feasible approach for achieving plant facilities and equipment design for maintainability. Each step is identified below, together with the years after start when the steps should occur, plus the identification of any unique resources.

Step 1: Develop Regulatory Guidance for Plant Facility and Equipment Maintenance Human Engineering Design. A regulatory guide should be developed to provide guidance to the utilities primarily for future design but also for review of the designs of

current plants with respect to good human factors engineering practices for enhancing maintainability. The guidance document can be built upon Canadian and U.S. handbooks which are accepted practice, e.g., U.S. Military Standard 1472-C; *The Human Engineering Guide to Equipment Design* by Van Cott and Kinkade, 1972; The U.S. Air Force Design Handbook Series, AFSC DH1-3 and 1-9. Related to this guidance is the topic of guidance with respect to protective garments, tools, and instrumentation for use in a radioactive environment. The adequacy of these items in the CANDU plants is not known by the authors. However, we can suggest that where improvements are warranted, a substantial amount of relevant research is being undertaken by the Electric Power Research Institute (EPRI) in Palo Alto, California. The development of the necessary regulatory guidance should take place in the first two years after start of this program.

Step 2: Maintainability Design Reviews. It is recommended that the majority of reviews for maintainability design with respect to human factors be conducted on a voluntary basis by utilities using the AECB guidelines. Where an analysis of significant event reports or observation of specific maintainability problems is observed by AECB inspectors, then specific guidance should be given to all inspectors to review the generic problem at all plants. This effort can be conducted on a more or less continual basis but will be most effective from the third year on, after the program starts and the regulatory guidelines recommended in Step 1 are available.

Dependencies

None.

Resources

Step 1--2 1/2 PMY; 2 PMY Human Factors and 1/2 PMY mechanical engineer. Step 2 intermittent minimal time of AECB staff. No other unique facilities or equipment are required for this program.

Procedures and Operator Aids

This recommendation is based on achieving the goal described in Section 4.8--The Development and Updating of Normal and Emergency Operational Procedures, Maintenance Procedures, and Operator Aids that are Technically Accurate and Optimally Comprehensible.

Technical Requirement

The technical requirement is to eliminate or minimize both procedural errors and performance time in the utilization of procedures and operator aids. This will be accomplished principally through the preparation and implementation of a procedure specification covering all phases of procedure development and use thereby increasing procedure development consistency and utilization reliability.

Importance

Medium to high; the importance can only be reasonably assessed after a review of some representative samples of current procedures which was beyond the scope of the current effort.

Schedule

Urgency: 3 to 5 years.

Duration: 3 years.

Implementation

Two separate steps are considered necessary to achieve acceptable procedures and investigate the feasibility of other

operator aids. Each step is identified below together with the years after start when the principle effort for the steps should occur.

Step 1: Develop a Specification for the Preparation of Emergency Operating Procedures. A specification should be developed to provide guidance to the utilities for procuring and/or preparing emergency operating procedures incorporating good human factors engineering practices. A good deal of related research and development has been done in this area and the specification could be based on the work of the U.S. Nuclear Regulatory Commission documented in NUREG-0899, Criteria for Preparation of Emergency Operation Procedures. Other related work is also being performed by the Institute of Nuclear Power Operations in the United States.

Step 2: Undertake Exploratory Operator Aids Research. Exploratory research should be undertaken to determine the value of advanced operator aids using computer-based information systems and multifunction electronic displays. The question to be answered in this research would be the value of these displays in enhancing operator detection and decisionmaking tasks with respect to off-normal occurrences. Two classes of systems seem to offer some potential with respect to safety effectiveness. The first would be safety vector status displays. This can be patterned after the work done in the United States on the safety parameter display system (SPDS) by the U.S. NRC, and EPRI. The second would be a disturbance analysis and surveillance system (DASS) which is a more sophisticated system which would not only provide status information but more diagnostic information to the operator in a prioritized order of importance such that plant safety and availability are improved. The Electric Power Research Institute in the

United States has been sponsoring work on this type of system. This effort can be accomplished as part of a general research effort in the second and third years of the program.

Dependencies

None.

Resources

Step 1: Human Factors Professional, 1/2 PMY; Emergency Procedures Specialist, 1/2 PMY. Step 2: Human Factors Professional, 2 PMY; Display Engineer, 2 PMY. Facilities for computer-driven flat panel display research.

Human Error Reporting System

This recommendation is based on achieving the goal of an operator error reporting system that provides the input to a data base of human error information by type, cause, and probable consequence of error for use in risk assessments and in evaluating changes and improvements in such areas as procedures, control room, and maintenance design.

Technical Requirement

The technical requirement is to develop a reporting system that is easily used by operating and maintenance personnel, that protects the identification of the reporter from censure, and that provides input to a data base that permits a variety of statistical analyses of human error to be undertaken.

Importance

High.

Schedule

Urgency: 1 to 2 years.

Duration: 1 year.

Implementation

To evaluate and improve the existing significant event reporting system, the following steps should be undertaken.

Step 1: Evaluate the Existing System to Identify Strengths and Weaknesses. The existing Significant Event Reporting System should be evaluated by human factors specialists to determine the extent to which it provides adequate instruction to users in completing the forms and in providing categories for data entry that classify error by type (e.g., errors of omission, commission, timing, and order) and probable cause. Software and personnel capabilities for managing accumulated data and for performing statistical analyses should be assessed and areas for improvement noted. Existing programs for the periodic extraction, analysis, and reporting of accumulated human error data to design, operational, utility management, risk assessment, and regulatory personnel should be evaluated and areas in which improvements can be made should be identified.

Step 2: Modification and Trial Use of Improved System. Based on the evaluation conducted in Step 1, the existing system should be modified, personnel trained in its use, and a trial period of use should begin. Periodic review of the accumulated data should be done jointly by users of significant event data and improvements made in the reporting format, instructions, and software analysis routines.

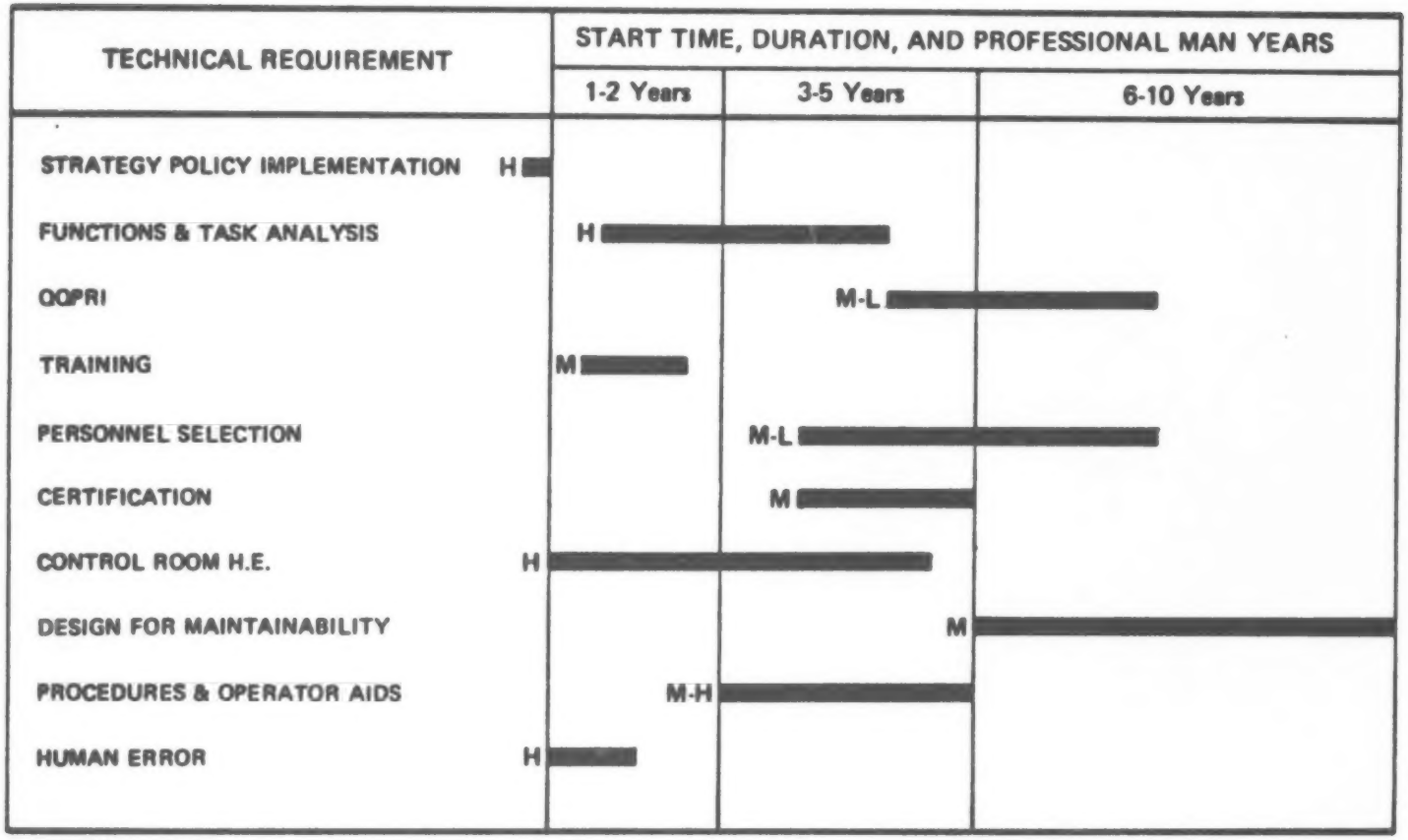
Dependencies

None.

Resources

Human factors professional: 1/4 PMY Step 1; 1/4 PMY Step 2. Other personnel from management, risk assessment, quality assurance, training, and certification--both industry and the AECB--should also be involved in both steps.

Exhibit 6.1
Schedule for Meeting Recommended Human Factors Plan



PRIORITY LEGEND
H = HIGH
M = MEDIUM
L = LOW

CONCLUSIONS

Presentations and papers prepared by staff of the Atomic Energy Control Board demonstrate that for some time the Board has been keenly aware of the relationship of human error to plant safety. Many of these documents contain recommendations for activities that would prevent or minimize human error. Responsibility and authority for consideration of human factors by the Board is also well-founded in the Atomic Energy Control Act and in regulations administered by the Board. Nevertheless, to date no consensus has been reached nor any strategy developed for defining and implementing the Board's role in human factors research and regulatory action.

A program of human factors research and regulatory action in nine human factors areas is recommended. Priorities, resource requirements and schedules are suggested for each area. Some of the areas of the proposed program should be undertaken by the AECB; others fall more clearly within the responsibility of the industry.

The three areas with the highest priority are: (1) the development and maintenance of an up-to-date description of the functions and tasks of plant personnel, (2) the design and layout of the work environment and man-machine interfaces in the control room to support operator performance and minimize error, and (3) the development and use of a significant event report system to permit the compilation and analysis of records of human error by type, probable cause, and potential consequences.

In general, the role of industry in undertaking human factors activities is seen as one of human factors design, development, and review, while that of the Board is regarded as one of developing criteria and standards, and auditing to determine compliance.

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APPENDIX 1

QUALIFICATIONS OF A HUMAN FACTORS SPECIALIST

Formal Education

A degree, preferably at the graduate level, in human factors engineering or engineering psychology is recommended. However, qualified human factors specialists may have received their formal training in other disciplines ranging from the behavioral sciences to engineering; therefore, the pertinent formal training requirements for human factors specialists should include course work in the following areas:

- Human factors engineering
- Ergonomics
- Human performance theory
- Sensory/perceptual processes
- Experimental design
- Quantitative methods/statistics
- Anthropometry
- Survey design
- Industrial engineering/design.

Professional Experience

Since there is no single academic route, certification, or licensing requirement for qualifying as a human factors specialist, the past professional experience of a prospective team member should be taken into account. As a guideline, five or more years of experience is recommended for a lead role. Less experienced human factors personnel may effectively conduct review activities with direction/advisory guidance from a senior human factors specialist.

Previous experience in process control system design and operations is preferred. Demonstration of extensive hands-on experience in the application of human factors engineering and human factors psychology to other large, complex man-machine systems (e.g., command and control systems, submarine control-display layouts) would be an acceptable alternative.

Preferred specific experience should include the application of human factors to design and/or evaluation in the following areas:

- Workspace layout
- Panel design (control and display layout)
- Environmental conditions (e.g., lighting and acoustics)
- Procedures and training.

Experience in systems analysis and task analysis should also be demonstrated within the complement of human factors professionals on the team.

APPENDIX 2

STANDARDS, GUIDELINES, AND PRACTICES RELEVANT TO HUMAN FACTORS AND NUCLEAR POWER

- *NUREG-0700--Guidelines for Control Room Design Review
- NUREG-0899--Draft Criteria for Preparation of Emergency Operating Procedures
- NUREG-0801--Evaluation Criteria for Control Room Design Reviews
- NUREG-0835--Human Factors Acceptance Criteria for SPDS
- NUREG-1750--Analysis, Conclusions, and Recommendations Concerning Operating Licensing
- NUREG-1764--Review of Staffing Requirements for Near-Term Operating License Facilities
- NUREG-1970--Development of a Checklist for Evaluating Emergency Procedures Used in Nuclear Power Plants
- NUREG-1368--Development of a Checklist for Evaluating Maintenance, Test, and Calibration Procedures Used in Nuclear Power Plants
- IEEE Recommended Practice for the Design of Display and Control Facilities for Central Control Rooms of Nuclear Power Generating Stations. IEEE Std. 566-1977.
- IEEE Trial-Use Standard Criteria for the Design of the Control Room Complex for a Nuclear Power Generating Station. ANSI/IEEE Std. 567 (draft), issued October 1980.

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*This document has an extensive appendix of reference materials that concern human factors engineering.

- *ORNL 62B-13819C/62X-11--Review of Standards and Requirements Affecting Human Factors in Nuclear Power Plant Control Rooms.

*This Oak Ridge National Laboratory's document has a review of all IEEE and ANS standards that apply to operator-system interaction.